C & C TECHNOLOGIES, INC.

A TECHNICAL REPORT

on

PHASE 1: TELEMETRY SYSTEMS RESEARCH

for

NRL CONTRACT N00014-94-C-6005

AUGUST 18, 1994

Approved for public release;
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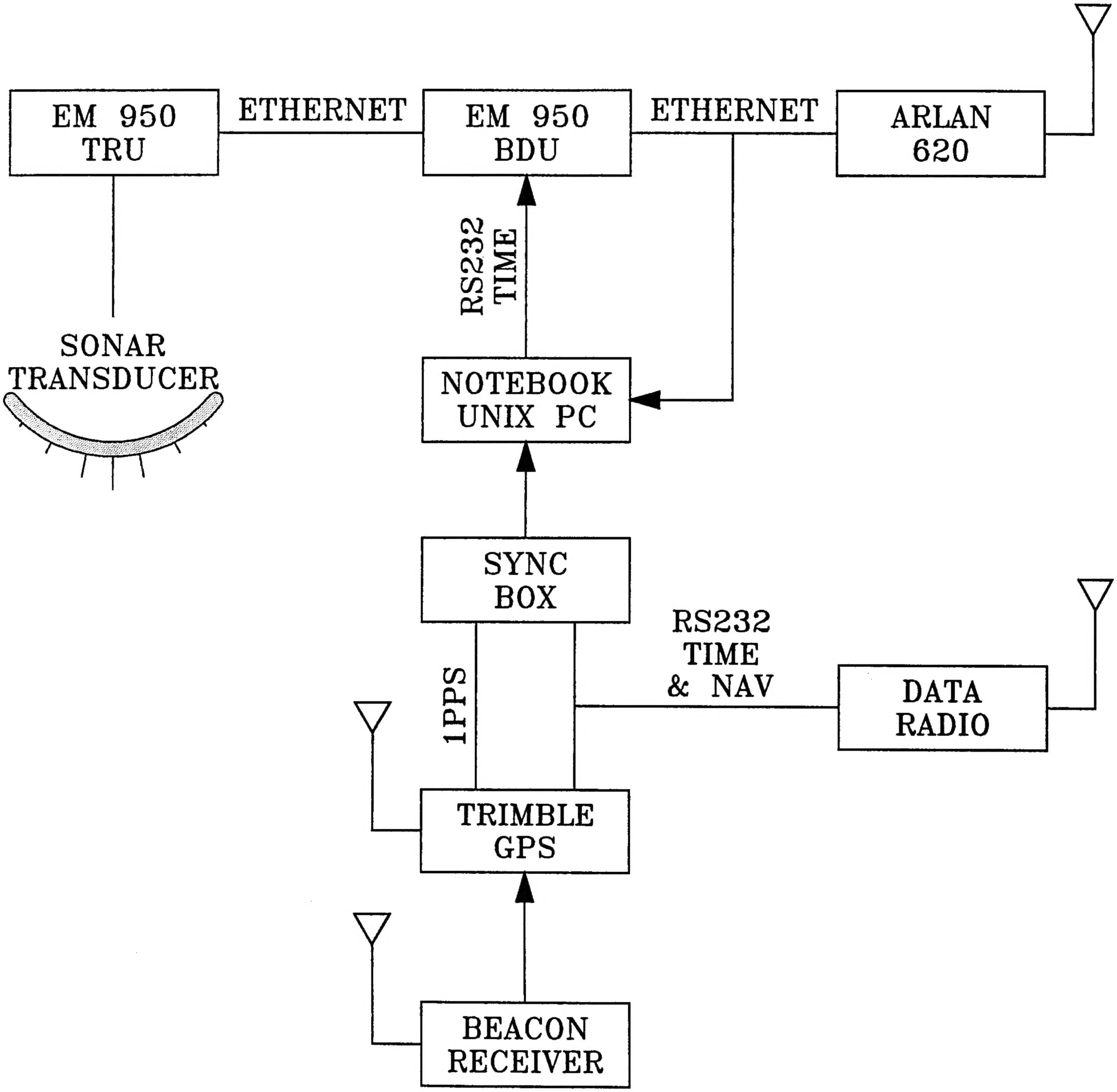
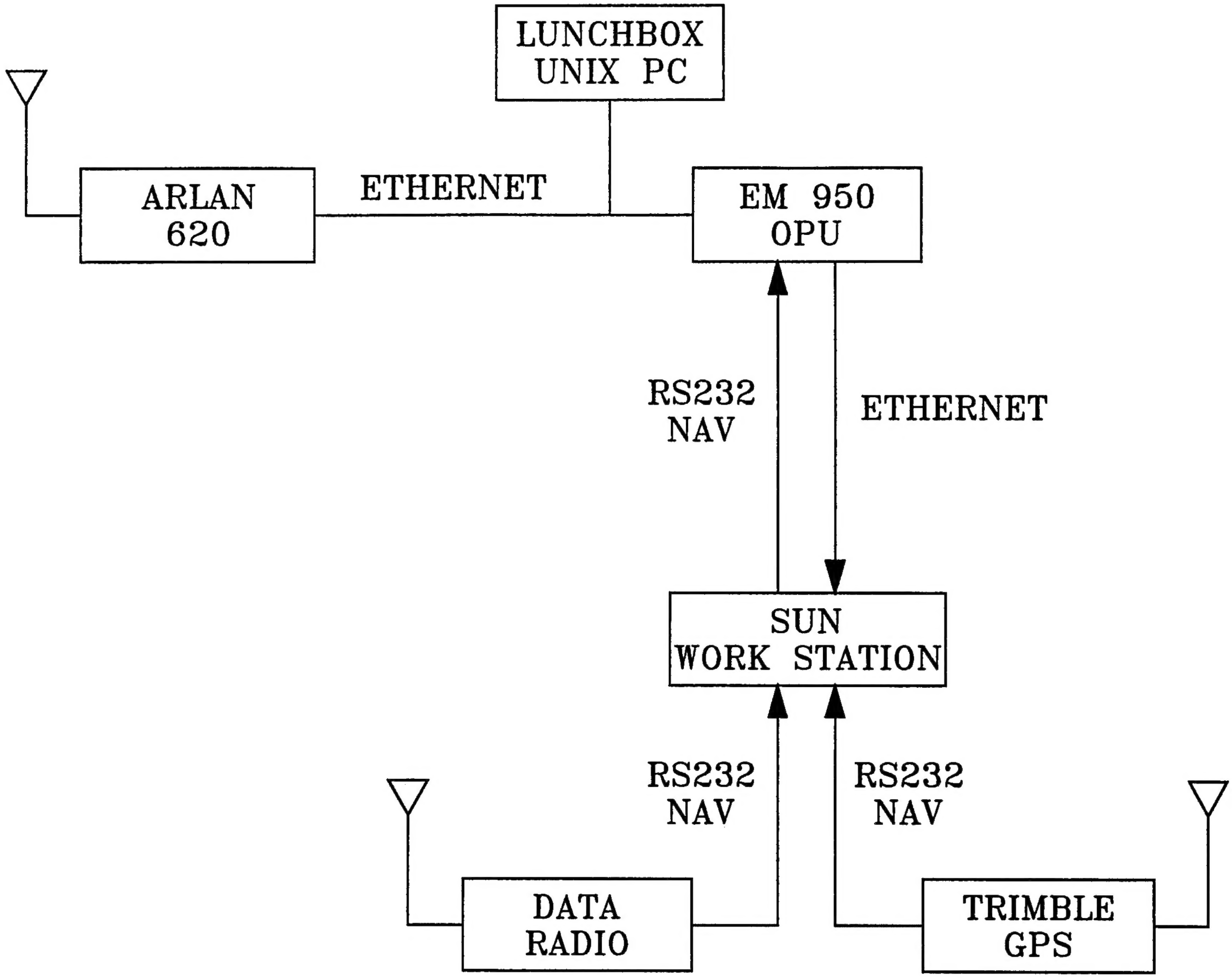
INLAND SURVEYOR



ATTACHMENT 1

FILE: NAVY

COASTAL SURVEYOR



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ATTACHMENT 2

FILE: NAVY

GENERAL

In support of the Naval Research Laboratory's Sea Lion program to instrument the remotely operated vehicles with multibeam bathymetry and imagery systems, it is necessary to demonstrate a telemetry system capable of handling the high data rates characteristic of this sensor suite at ranges of several miles on moving platforms. The telemetry system will have the capacity to deliver data at very high rates (possibly up to 8 megabits per second). Such a system will facilitate the relay of bathymetric data from the Sea Lions to a mother ship.

SEA LION TELEMETRY SYSTEMS REQUIREMENTS (Task 1)

Task 1 of Contract N00014-94-P-6601 states "The contractor shall determine the expected data rate requirements and system integration criteria for the Sea Lion telemetry system". This report will outline these requirements and considerations/rationale for the parameters set by C & C Technologies, Inc. personnel.

DATA RATE:

The minimum acceptable data rate is 256 kbps. The rationale for this rate is as follows:

1. Simrad Corporation personnel have stated that the theoretical maximum data rate for the Simrad EM 950 is 150 kbps. See attached FAX.

2. Typical data rates for telemetry systems investigated for this project ranged from 9600 bps, 128 kbps, 256 kbps, 512 kbps, 1.5 Mbps, and a high of 10 Mbps. A data rate of 256 kbps leaves some room for potential growth requirements in sensors and instrumentation. This would also provide a buffer to backfill gaps in communications without causing excessive delays in realtime data transfer.

INTEGRATION CRITERIA:

The Simrad EM 950 Multibeam system components are interconnected via an Ethernet LAN. The integration requirements are driven by the physical and protocol interface requirements of this LAN. Telemetry systems must provide a transparent interface to Ethernet IEEE 802.3 (TCP/IP) and physical connection to 10 base 2.

RANGE:

Currently Geo-Resources, Inc. has a 5 kilometer telemetry range, NRL and NAVO have expressed a desire to extend the range as much as possible. Initial indications are that transmit power of one watt for L band and as near to one watt as possible for S band spread spectrum systems is highly desirable. Additional range will have to be achieved through antenna systems.

LICENSING REQUIREMENTS:

It is necessary to keep the power at one watt or less due to FCC licensing requirements. Licensing would cause delays in excess of 180 days. Currently, spread spectrum systems with transmit power of one watt or less are not required to be licensed. Licensing requirements are expected to change in June of 1994, however, transmitters manufactured prior to this time will be grandfathered.

RELIABILITY:

Narrow band and spread spectrum telemetry systems have the through-put capacity to meet the data rate requirements. These systems were compared for reliability characteristics. Spread spectrum systems are considered to be more reliable than narrow band systems for the following reasons:

1. Narrow band systems are susceptible to multipath loss particularly at low angles over water, whereas, spread spectrum systems are more tolerant.

2. Spread spectrum systems are much less susceptible to interference.

3. Spread spectrum systems are much less susceptible to signal fade losses due to weather conditions.

4. Narrow band systems are composed of individual components such as transmitter, receiver, pre-modulation filter assembly, PCM to FSK encoder, packet bit synchronizer, and ethernet bridge. Spread spectrum systems are self contained or at most require a ethernet bridge. Fewer components, less cabling and fewer connectors introduce fewer trouble points in spread spectrum systems than in narrow band systems.

5. Spread spectrum systems generally transmit less than one watt. Current FCC guidelines state that systems transmitting one watt or less do not require a license. Additionally, the possibility of interfering with other systems is minimal.

POWER REQUIREMENTS:

The telemetry system must be capable of operating on a voltage that is capable of being generated by or derived from the existing 24 volt DC power source currently on the Sea Lions.

CHANNEL CAPACITY:

The telemetry system must have sufficient band width and signal discretion to support operation of two or more discrete channels simultaneously in order to support sensors, in addition to the Simrad EM 950, that are expected to be integrated into the Sea Lions.

AVAILABILITY:

The telemetry system must be readily available off-the-shelf technology. Custom designed systems require long lead times, often in excess of 180 days. Long lead times will not allow for completion of the overall Sea Lion project within the time lines projected by NRL. Narrow band systems tend to be custom designed systems, whereas spread spectrum systems are off-the-shelf technology requiring no custom design work.

COST:

Typical costs for narrow band telemetry systems are in excess of $150,000.00. Typical costs for spread spectrum systems are under $30,000.00.

SEA LION TELEMETRY SYSTEMS ANALYSIS (Task 2)

Task 2 of Contract N00014-94-P-6601 states "The contractor shall research and determine what telemetry systems are commercially available with regard to high data rate telemetry systems, their specifications, leadtimes, and costs. The commercial systems shall be ranked from the compiled information. Factors for consideration are: (1) data rates; (2) transmission methods; (3) software compatibility; (4) hardware configuration; (5) anticipated reliability; and, (6) cost.". This report will outline the results of our investigation of the commercial availability of telemetry systems capable of meeting the technical requirements of the Sea Lion project..

Criteria searched:

1) Data rate
2) Transmission method
3) Software Compatibility
4) Hardware configuration
5) Anticipated reliability
6) Cost
7) Lead time
8) Availability of evaluation units

Two types of transmission systems were identified and investigated, narrow band and spread spectrum systems. A desk top comparison was made between the two types of systems to determine which technology best suits the Sea Lion project requirements. A summary follows:

Narrow-band with space diversity combination reception.

1) Up to 10 Mbits/sec.
2) Narrow-band FSK modulated microwave carrier utilizing space diversity reception.
3) Compatible with most LAN transmission formats utilizing a bridge interface.

4) Numerous discrete components, more cabling and space required.
5) Anticipate more maintenance due to number of components in system, with less link reliability.
6) Over $100,000.
7) Quoted 180 days to gather all components in system.
8) Not readily available off the shelf.

Spread Spectrum.

1) 256 Kbits/sec minimum, up to 2Mbits utilizing compression.
2) Spread spectrum, direct sequence spreading modulation.
3) Compatible with most LAN transmission formats utilizing a bridge interface.
4) Fewer components, greater system integration, less cabling and space required..
5) Anticipate less physical maintenance with greater link reliability.
6) Under $30,000.
7) Normally only the time required to ship from the factory.
8) Available off the shelf, determined by manufacturers willingness to participate.

Representative narrow band telemetry system price and component breakdown as quoted from *Broadcast Microwave Services, Inc.*

Narrow-band telemetry system with space diversity combination receiver, Sea Lion mobile terminal.

Quantity	Item	Unit price	Total price
1	6 db Omni Antenna	$ 2,650.00	$ 2,650.00
1	Antenna diplexer and circulator assembly	$ 4,450.00	$ 4,450.00
1	Command Receiver, L band	$14,800.00	$14,800.00
1	Video / Data Transmitter, L band, 10 watts	$12,700.00	$12,700.00
1	Pre-modulation filter assembly	$ 3,950.00	$ 3,950.00
2	PCM / FSK encoder / decoder	$ 1,950.00	$ 3,900.00
2	Frame / packet bit synchronizer	$ 2,600.00	$ 5,200.00
1	Translation Bridge	$ 4,200.00	$ 4,200.00
		Total:	$51,850.00

Shipboard control terminal

Quantity	Item	Unit price	Total price
2	6 db Omni Antenna	$ 2,650.00	$ 5,300.00
2	Antenna diplexer and circulator assembly	$ 4,450.00	$ 8,900.00
2	Command Receiver, L band	$14,800.00	$29,600.00
1	Video / Data Transmitter, L band, 10 watts	$12,700.00	$12,700.00

1	1200 MRC diversity combiner	$26,127.00	$26,127.00
1	Pre-modulation filter assembly	$ 3,950.00	$ 3,950.00
2	PCM / FSK encoder / decoder	$ 1,950.00	$ 3,900.00
2	Frame / packet, bit synchronizer	$ 2,600.00	$ 5,200.00
1	Translation Bridge	$ 4,200.00	$ 4,200.00
		Total:	$99,877.00

Overall narrow-band telemetry system total price: $151,727.00

Representative spread spectrum telemetry system price and component breakdown as quoted from *Cylink*.

Quantity	Item	Unit Price	Total Price
2	Airlink 256 Digital Spread Spectrum Radio	$3,195.00	$6,390.00
2	Gandalf Bridge with Optimizer Software	$2,100.00	$4,200.00
2	Antennas, Omni, 860-940 Mhz.	$ 866.00	$1,732.00
		Overall Total:	$12,322.00

NARROW BAND

Ayden Vector / Walt Schelmet
Loral Conic / Al Hackstaff
Berg Systems / Pete Kelly
AP Labs / Rich Grohal
Microdyne / Dwight Turner
California Microwave / Jerry Vettrus
Emhiser Research, Inc./ Jay Lawson
Militech Corp/ Dean Dixon
BMS/ R. B. Anderson

SPREAD SPECTRUM

Digital Radio Corp / Arvin Perry
Proxim Inc / Tom Mitchels
Cylink / Mickey Marks
Western Multiplex Corp. / Harold Rhodes
Aironet / Tim Clark
Solectek Corp / Dean Fledderjohn
Harris Corp / Byron Knight

These criteria and telemetry systems were discussed in a meeting between C & C Technologies and NRL personnel. Spread spectrum technology was determined to be best suited for the Sea Lion Project based on the criteria noted above and that spread spectrum systems investigated do not require an FCC license. Narrow band systems do require an FCC license. Mr. Harris and his staff at NRL determined that the requirement for a license would cause unacceptable delaysin the Sea Lion project in that the process takes in excess of 180 days.

SPREAD SPECTRUM TELEMETRY SYSTEMS WERE RANKED AS FOLLOWS:

System price and component breakdown as quoted from *Cylink*.

Quantity	Item	Unit Price	Total Price
2	Airlink 256 Digital Spread Spectrum Radio	$3,195.00	$6,390.00
2	Gandalf Bridge with Optimizer Software	$2,100.00	$4,200.00
2	Antennas, Omni, 860-940 Mhz.	$ 866.00	$1,732.00
		Overall Total:	$12,322.00

Specifications

Cylink Airlink 256

Data rate:	Raw data transfer rate of 256 thousand bits / second
Frequency:	902-928 Megahertz. (L band)
Power output:	1 Watt transmitter power
System (spreading) gain:	119 db
Effective range:	Measured out to 3.0 miles
Physical size:	2.125" high x 8.5" wide x 10.5" length
Weight:	8.5 pounds
System hardware:	Radio, bridge, antenna, coax cable and interconnect wiring
Power requirements:	120 VAC
Power consumption:	20 watts

System price and component breakdown as quoted from *Aironet.*

Quantity	Item	Unit Price	Total Price
2	Arlan 620 Ethernet Bridges	$2,495.00	$4,990.00
2	Antennas, Omni, 860-940 Mhz	$ 866.00	$1,732.00
		Overall Total	$6,722.00

Specifications

Solectek Airlan

Data rate:	Raw data transfer rate of 2 Million bits / second
Frequency:	902-928 Megahertz (L band)
Power output:	250 Milliwatts
System (spreading) gain:	na
Effective range:	untested, predicted to be 1.5 miles
Physical size:	3.4" high x 13.0" wide x 15.7" length
Weight:	14 pounds
System hardware:	Radio, Antenna, Coax and interconnecting wiring

Power requirements:	120 VAC
Power consumption:	73 watts

System price and component breakdown as quoted from *Solectek.*

Quantity	Item	Unit Price	Total Price
2	AIRLAN/BRIDGE	$4,999.00	$9,998.00
2	3ft antenna cable and connectors	$ 49.00	$ 98.00
2	Antennas, Omni, 860-940 Mhz	$ 866.00	$1,732.00
		Overall Total	$11,828.00

Specifications
Aironet Arlan 620

Data rate:	Up to 1.35 Million bits / second
Frequency:	902-928 Megahertz (L band)
Power output:	1 Watt transmitter power
System (spreading) gain:	N/A
Effective range:	predicted to be up to 3 miles
Physical size:	1.9" high x 9.6" wide x 9.6" length
Weight:	3 pounds
System hardware:	Radio, Coax cable, antenna, various interconnect cables
Power requirements:	125 volts AC
Power consumption:	N/A

SEA LION TELEMETRY SYSTEMS INVESTIGATED (Task 3)

Task 3 of Contract N00014-94-P-6601 states "The contractor shall test the top two or more telemetry systems. This shall require the design of telemetry tests to simulate conditions anticipated with the NRL Sea Lions. This shall also include the development of a test to quantitatively evaluate the various telemetry systems with regards to critical parameters such as data rates and error rates. The telemetry test setup shall include the following: (1) preparation of test software; (2) hardware; (3) power supplies; (4) antenna mounts; (5) range reconnaissance; and any other functions to assist in evaluating the performance of the telemetry systems. Initial testing of telemetry systems shall be executed in the laboratory to insure that the systems are properly interfaced. Throughput of high density SIMRAD EM950 data shall be employed".

INTRODUCTION

Laboratory tests were performed on data radios selected for evaluation for use on the ORCA vehicles.

The radios were the Cylink Airlink 256 with a Retix ethernet Bridge, and the Telesystems Arlan 620.

LAB TESTS

The data radios were installed on UNIX workstations, providing an ethernet link between the computers. Two 4 db omni-directional antennas were used inside the laboratory building connected to the radios with 50 feet of low loss coaxial cable. Each radio was connected to a single workstations, with no other computers on the network.

The ethernet link was first verified using standard UNIX networking commands. The ping command was used to measure round trip data latency and data loss. The rcp command was used to transfer large files, verifying that the link support high data rates and reliable data transfers. Netstat was used to verify that no network errors occurred during the tests.

Software was written to send continuous data across the radios with ping and netstat running to measure data error rates. The tests were performed for 24 continuous hours on each radio set. Both radio sets ran the test with no errors. The Cylink had a data transfer rate of 200 kb/s and the Arlan had a transfer rate of 250 kb/s. The data rates were determined by measuring the time required to copy large files with the rcp command.

A Simrad EM 950 simulator program was used to test the radio links. The simulator program was developed by C & C Technologies to test the EM 950 systems and software. The simulator sends actual EM 950 data over the ethernet with the data rate and timing adjusted to match the speed and timing of the EM 950. The simulator program was run on one of the two workstations.

The data was collected and analyzed on the second workstation, which was running HydroMap. HydroMap is a data collection and processing system written by C & C Technologies for use with the Simrad EM 950. The data collected by the program was compared to the original data sent by the simulator and found to be identical. HydroMap performs several data integrity checks, and found no errors in the test data. Netstat and ping were run while the tests were performed. Neither program detected any network errors.

Both data radio sets performed flawlessly. No data error were found. The data rates were sufficient for operation of the EM 950 and the data latencies were similar to those on direct wired ethernet.

SEA LION TELEMETRY SYSTEMS INVESTIGATED (Task 4)

Task 4 of Contract N00014-94-P-6601 states "The contractor shall conduct field tests with the sensors selected in Task 3 over various base line lengths and environmental conditions to thoroughly analyze the capabilities of selected units. This shall be accomplished by utilizing the

INLAND SURVEYOR as a test platform to produce high density bathymetry and imagery data, true Sea Lion operational simulations will be effected. The contractor shall record data and evaluate parameters in this task. This task shall include required software development, electronics, hardware development and collection efforts".

INTRODUCTION

The study was performed to identify a data radio which could be used on the ORCA vehicle to operate the Simrad EM 950 multibeam echosounder. Most of the components of the EM 950 will be installed on the ORCA, while the operator unit and data collector computer will be installed on a mother ship.

The Simrad EM 950 sends data over 10base2 ethernet to the operator unit. The maximum theoretical data rate, as specified by Simrad engineers, is 150 kb/s. A small amount of data is sent from the operator unit to the ORCA when the operator gives commands. The data is sent with UDP broadcasts, which have no error correction or retransmission abilities. The radio link must provide all error correction and present a transparent reliable link.

The data radio must operate reliably over water with any sea state. Multipath is a major problem with most data radios operating over water. Both of the radios tested are spread spectrum radios. Spread spectrum radios tend to be mostly immune to multipath. In higher seas, the line-of-sight path may be blocked by tall waves at regular intervals. The radio should be able to transfer data during the fraction of the wave period when line of sight path is clear.

It is preferred that the radios operate with omni-directional antennas on both ends. To obtain longer ranges, a tracking directional antenna could be placed on the mothership.

Two high speed, spread spectrum data radios were selected for testing. Both radios operate in the L band (915 Mhz), transmit 1 watt of power, and operate bi-directionally.

The Cylink Airlink 256 has a maximum data rate of 256 kilobits per second (kb/s) and uses the entire bandwidth for the one channel. Only one pair of radios can operate in an area at one time unless directional antennas are used to separate the signals. The Cylink has a V.35 data interface and requires an ethernet bridge to connect to 10base2 ethernet. It requires a 120 volt AC power supply.

The Telesystems Arlan 620 can be set to operate on one of 14 channels. Six of the channels operate on separate non-overlapping sub-bands at a data rate of 215 kb/s. Three channels operate on separate sub-bands at 344 kb/s. Five of the channels operate using the full bandwidth at rates from 630 kb/s to 1350 kb/s. The Arlan has a built-in 10base2 interface. It operates on 24 volts DC supplied by a small AC adapter.

EVALUATION: SEA TEST

A test was setup to emulate the operations of the ORCA vehicle. The Inland Surveyor was used as a roaming platform. On the boat were an EM 950, a UNIX notebook computer, and the radio gear. The radios used a 4 db omni-directional antenna mounted on the cabin of the vessel, about 6 feet above the waterline. The antenna was attached with 25 feet of low loss RG-8 coax cable (Belden 9913).

The radios linked to a network on the boat with the Simrad Bottom Detector Unit (BDU) and the notebook computer.

The base station was setup on Cypremort Point. The computer equipment included the Simrad Operator Unit (OPU) and a Sun Workstation. A 9 db omni-directional antenna was mounted on a mobile mast and elevated to 45 feet above ground level. The antenna cable was 50 feet of low loss RG-8 coax cable (Belden 9913).

Testing was performed by operating the Simrad echosounder over the radio link and running the ping program on the UNIX computers. The data collector on the Sun workstation verifies sequence numbers in the datagrams collected from the EM 950 and sounds an alarms when data is lost. Ping measures the round trip latency time of the data between the computers.

First, the equipment was setup and tested at the dock. The operation of the EM 950 appeared normal. It operated just as it does with a direct connection instead of the radio link. No data was being lost. Communication between the UNIX computers was verified. The tests were performed for both radios, manually switching between radios.

The boat sailed to varying distances from the base station and the performance of each radio was noted.

The re-acquisition time was measured for each radio. The test was done by removing the antenna cable, then re-connecting the cable and noting the time for data transfer to resume. The time did not change as the distance increased. The re-acquisition time for the Cylink with the Retix bridge was 20 seconds. The time for the Arlan was always too short to be measured, estimated to be less than 200 ms. The Cylink would drop all data sent when the link was down. The Arlan would retain the data and burst transmit when the link was established.

The first test distance was 1 nautical mile (nm). At this distance the EM 950 operated normally with both radios. No lost packets were detected. The Cylink had a round trip ping time of 20 - 70 ms, and the Arlan 25 - 100 ms. The ping time stabilized at 20 ms for both radios if the EM 950 transmitted no data. The Arlan was operating on channel 12, which has a data rate of 946 kb/s.

The Cylink radio was in operation during the transit from 1 nm to 2 nm. The radio lost link twice during the trip.

At 2 nm the Cylink operated with no problems. The round trip ping time was 20 - 100 ms. The performance of the Arlan was much degraded, even losing link for 50 seconds at one point. The unit was switched from channel 12 (946 kb/s) to channel 0 (215 kb/s). The data link was reliable at the lower data rate.

At 3 nm it was found that the link reliability for both radios depended on the heading of the boat. The link was weaker when the boat headed away from the base station. It is thought that the air-conditioners, which were behind the antenna, affected the performance. The antenna was raised about 18 inches and the heading dependency was reduced. The radio link also degraded when the boat rolled heavily in the seas and when the boat had a large amount of squat. The data link was sufficient to operate the EM 950 with either radio when the boat faced any favorable direction.

The radio links were evaluated again at a range of 3.5 nm. The Arlan had an erratic link that faded in and out. All the available channels were tested. All the 215 kb/s channels had the same erratic performance. The radio could not establish a link on any of the channels which operated at a higher data rate. The Cylink would lose lock on the radio link every few minutes, and the link would take 20 seconds to return. Switching the Cylink to 224 kb/s from 256 kb/s did not improve the link. The performance of both radios was unacceptable for operation of the EM 950.

EVALUATION: LAND TEST

A second test was performed to evaluate the performance difference between a 9 db omni-directional antenna and a 12 db directional yagi antenna.

The test was conducted along a rural highway near Church Point, LA. A base station was established on the side of the road with both antennas mounted on a 45 foot mobile tower. A truck was used as a mobile station with a 4 db omni-directional antenna mounted on the top. The base and the mobile stations both had UNIX notebook computers attached to the high speed radios.

Along the road were several obstructions. Scattered rural power lines ran along the road and crossed the road in several places. The road was mostly clear of trees, but there were trees within 50 feet of the road in a few places.

Tests were run at varying separation distances. Again, the ping program was run to measure round trip data latency. Rcp was used to time the transfer of large data sets in order to measure the data rate.

Discussions with engineers at Retix, the manufacturer of the bridges used with the Cylink radios, lead to the conclusion that the reacquisition time could be improved. The unit performs a warm

reset when it detects that the V.35 link is down. By default, the units performs several diagnostic tests after a reset. Most of the tests were disabled for warm resets to improve the reacquisition time.

The reacquisition time was measured for each unit. The antenna cable was disconnected, then reconnected and the amount of time for data flow to resume was measured. The Cylink with the Retix bridge took 11 seconds to reacquire the link. The Arlan data flow resumed almost immediately, too fast to be measured. The Cylink lost all data transmitted from the time the data link was lost until the time the link was reacquired. The Arlan appears to have a buffer of about 1MB and will not lose data unless the buffer overflows.

The first measurements were taken with a separation distance of 1.36 statute miles, as indicated by a Trimble Ensign GPS unit. Both radios worked well with both antennas. To verify proper operation of the radios and antennas, the ping program was run to measure round trip data latency time. The time was noted with no other traffic over the radio link.

A large file of several megabytes was transferred over the link using the rcp (Remote CoPy) command. The file transfer puts a heavy bi-directional load over the ethernet. The rcp command uses the TCP protocol. With this protocol, the sending computer sends a data packet and then waits for an acknowledge from the receiving computer. The TCP protocol usually has a much lower transfer rate than the data rate of the physical link because of the latencies of the acknowledge packets. The UDP protocol used by the Simrad EM 950 does not have any acknowledge packets and will usually transfer at near the data rate of the physical link.

Radio	no load ping time	ping time rcp running
Cylink:	20-30ms	30-160ms
Arlan:	30ms	30-200ms

The mobile station was moved to a point along the road 3.00 statute miles from the base station.

System	no load ping time	ping time rcp running	Transfer rate
Cylink & Yagi:	20-30ms	30-160ms	178 kb/s
Arlan & Yagi:	30ms	30-210ms	143 kb/s

The tests with the omni-directional antenna produced very poor results. The Arlan took 6 minutes to acquire the link, and the link was very erratic, dropping out for minutes at a time. The Cylink appeared to have a stronger radio link, but with each radio link dropout the Retix would reset, taking 11 seconds to resume. Both systems were unusable with the omni-directional antennas at this range.

The mobile station was moved to a point along the road 4.14 statute miles from the base station. At this time the weather was deteriorating and a light sprinkle began. No tests were performed with the omni-directional antenna at the base.

System	no load ping time	ping time rcp running	Transfer rate
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Cylink & Yagi:	30ms	30-170ms	178 kb/s
Arlan & Yagi:	20-30ms	40-220ms	145 kb/s

The mobile station was moved to a point along the road 5.14 statute miles from the base station. This was the maximum straight line distance available. A small power station with many power lines was between the mobile station and the base station (about 4.3 miles along the road from the base). The rain was becoming heavier. The Arlan had an erratic link with 30 - 350ms ping times with no load, and dropping about 10% of packets. The Cylink radios indicated that they were synched, but the Retix bridges could not establish a link.

CONCLUSIONS

Both radios were adequate to operate the Simrad EM 950 when they were in close range. The data rates were sufficient and the time delays were minimal.

The more interesting results are the failure modes of the radio links under adverse conditions. The Arlan would quickly transfer data anytime it could establish the radio link, and buffer data as long as it had buffer space. The Cylink radios would establish the radio link quickly, but the Retix bridge was much less robust with an erratic link.

The Arlan radio is recommended for the ORCA. It has good performance under adverse conditions. The compact, integrated design will fit well into the compact space, and it runs directly on 24 volts (the main power supply on the ORCA).

SUMMARY

Both radios were adequate to operate the Simrad EM 950 when they were in close range. The data rates were sufficient and the time delays were minimal.

The Arlan would quickly transfer data any time it could establish the radio link, and buffer data as long as it had buffer space. The compact, integrated design will fit well into the compact space, and it runs directly on 24 volts (the main power supply on the ORCA). The cost of the Arlan radios is lower than the price of the Cylink radios and the Cylinks require ethernet bridges which cost as much as the radios.

The Cylink radios would establish the radio link quickly, but the Retix bridge was much less robust with an erratic link. Both the radio and the bridge require 120 volt AC power, which is not available on the ORCA vehicles. The combined package is relatively large and cumbersome.

RECOMMENDATION

The Arlan radio is recommended for the ORCA vehicles based on performance, cost, size, and power requirements.

TELEMETRY SEA TRIALS

GENERAL

Requirements for this task are stated in proposal "B" which reads in part, 'The telemetry system previously identified and field tested under purchase Order N00014-94-P-6601 will be tested at sea with data generated from C & C Technologies' Simrad EM 950 multibeam bathemetry and imagery system. Transmissions will be made between the multibeam vessel and a second vessel. This will allow the range and conditions to vary as they would from the Sea Lion to the mother ship. Because antenna height is critical, additional testing may be performed with the second vessel dockside where the antenna height can be adjusted.

INTRODUCTION

The NRL ORCA vehicles are to be fitted with Simrad EM 950 multibeam swath sonar systems, and with Telesystems Arlan 620 high speed spread-spectrum data radios. Tests were performed to evaluate the performance of the EM 950 while operating over the Arlan data radio.

The Simrad EM 950 was not originally designed to operate over data radios. Several changes were made to the operating software of the multibeam system by the manufacturer to handle data latencies caused by the radio link. The new software was tested for the first time during the Sea Trials.

The operating range of the data radios was measured under varying conditions to determine the practical limits. The radios were tested with several different antennas with different antenna heights. Different radio channels and data rates were tested to determine the effect on range.

UNITS EVALUATED

Simrad EM 950

A Simrad EM 950 multibeam swath sonar system was the primary remote sensing device used

during the radio telemetry tests. The EM 950 was running new beta test software recently developed by Simrad. The Bottom Detect Unit (BDU) of the system was running version 2.31beta software, and the Operator Unit (OPU) was running 3.81beta.

Antennas

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7 db Omni (MFB-9387)	35 ft elevation	75 ft low loss coax (RG-8)
9 db Omni (ASPG 952)	20 ft elevation	75 ft low loss coax (RG-8)
4 db Omni (S8964B)	10 ft elevation	50 ft low loss coax (RG-8)
12 db yagi (YA5 900)	16 ft elevation	50 ft low loss coax (RG-8)

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7 db Omni (MFB-9387)	6 ft elevation	50 ft low loss coax (RG-8)
5 db Omni (MFB-8965)	6 ft elevation	50 ft low loss coax (RG-8)

Telemetry Link

The ARLAN 620 bridge attaches directly to an ethernet cable to provide bridging functions between two physically separate ethernet LANs.

EVALUATION

System Layout

Two boats were used to simulate the operation of the ORCA vehicle and the mother ship. The Inland Surveyor, a 24 foot survey launch, was used to simulate the ORCA vehicle. The Coastal Surveyor, a 40 foot survey launch, was used as the mother ship. The components of the EM 950 which will be installed on the ORCA were installed on the Inland Surveyor. See attachment 1 for a block diagram of the components. The components of the EM 950 that will be installed on the mother ship were installed on the Coastal Surveyor. See attachment 2 for a block diagram of the components.

Inland Surveyor

The EM 950 components on the Inland Surveyor included the sonar transducer, the sonar transceiver unit (TRU), and the BDU. Normally, the BDU is connected to the OPU via a hardwired 10base2 ethernet connection. For ORCA operations, a pair of Arlan 620's will provide the 10base2 connection so that the OPU can be installed on the mother ship. An Arlan 620 was attached to the BDU and also to an IBM PC compatible notebook computer running UNIX System V revision 4. The UNIX PC was used to measure data travel time over the radio link while the EM 950 was in operation.

Positioning equipment on the Inland Surveyor included a Trimble 4000SE Differential Global Positioning (DGPS) system, and a Coast Guard Beacon receiver for differential corrections. A Data Radio was connected to the DGPS receiver to broadcast the position of the launch. The DGPS also provided a precise time reference for the BDU.

Coastal Surveyor

The Coastal Surveyor was used as the mother ship. An Arlan 620 on the mother ship provided the data link to the EM 950 Operator Unit (OPU). Also on the network with the Arlan 620 was an IBM PC compatible lunchbox computer running UNIX System V revision 4. This lunchbox was running the UNIX ping program to constantly measure the round trip travel time to the notebook computer on the Inland Surveyor.

A Sun workstation running the HydroMap software package collected and processed the multibeam data generated by the OPU. A Data Radio received the broadcast DGPS positions from the Inland Surveyor and sent the data to the Sun workstation. A GPS receiver provided the position of the mother ship to the workstation so that the distance between the boats could be continuously calculated and displayed.

Tests Performed

The site chosen for testing was Southwest Pass of Vermillion Bay. The pass has water with depths from 1 meter to over thirty meters, and has a range of bottom types from soft silt to hard oyster reefs. The Inland Surveyor stayed just inside the pass for protection from the seas, and the Coastal Surveyor sailed south into the Gulf of Mexico such that there was no land mass between the two boats.

The seas in open water were running 2 to 3 feet with a southerly wind of about 15 knts. The seas in the pass and in the bay were calm. The weather conditions were partly cloudy and temperature was in the 90's. No precipitation was experienced during the test.

The Inland Surveyor ran survey lines in the pass as the Coastal Surveyor collected and processed the data. The Arlan 620 bridges were tested while operating on several of the different channels available, and with various antenna configurations. The maximum range of the radios was

measured while operating the swath sonar. Range limit was determined by increasing the distance between the vessels until the ethernet link deteriorated or was lost.

The Time synchronization of the EM 950 BDU was verified periodically during the several hours of testing. The BDU was always found to have excellent synchronization to the DGPS time.

Throughput statistics provided by the Arlan radio firmware indicated that the EM 950 was sometimes sustaining a data rate of up to 170 kbps. Simrad engineers had calculated that the maximum theoretical data rate that could be produced by the EM 950 was 150 kbps, however these calculations were done prior to the current software upgrade. The data rate from the EM 950 appeared to be much higher on this test than on previous radio telemetry trials.

It was found that the radio ethernet link operating on one of the 215 kbps channels could not always keep up with the data output of the EM 950. All of the channels with higher data rates (344 to 1350 kbps) were found to be sufficient to keep up with the EM 950.

The data latency of the radio ethernet link was measured by running the ping program on the UNIX PC on the Coastal Surveyor. The ping time was around 20 milliseconds when there was little traffic on the ethernet link, and would increase as the load increased. The data latency generally indicated how much data was being buffered. It was found that the Arlan could run at least 15 seconds behind the data output from the EM 950 without losing data.

The effect of the radar system on the Arlan 620 link was tested by measuring the range of the radios with the radar on and with the radar off. The radar had no effect on the range or on the transfer rate of the link.

The range of the Arlan radios was found to be independent of the operating channel and bandwidth of the channel. The limit of the operating range of the Arlan 620 was measured for channels in each of the available data rates. No significant differences were found.

Range Tests

Range tests were conducted with various antenna configurations, data rates (discrete channels), and sea conditions. It should be noted that while in open waters the antenna mast on the mother ship was experiencing up to a 40 degree whipping action . As noted above, the greatest antenna height during this test was 35 feet above the water. The expected mother ship (TAG 60) antenna height should be at least 60 feet above the water.

Overall the best link was established with 7db antennas on each vessel. The reliable range in this configuration was 3.3 km. At various stages of the tests the link would reestablish at greater ranges, i.e. 3.7 km and maintain link to 5 km. At one point during the test we had no connection at 4.9 km and regained connection at 5.1 km.

When using the 9db to a 7db antenna the range was 2.1 km. This reduced range is likely due

the lower antenna height of the 9db antenna, 20 ft vs 35 ft for the 7db on the Coastal Surveyor.

The 12db yagi antenna to the 7db omni configuration maintained link to 5 km as long as the antenna was properly oriented. Orientation was maintained solely by boat steering as the yagi was mounted solidly to the mast.

CONCLUSIONS

The Simrad EM 950 operates properly with the Arlan 620 ethernet bridges providing the data link between the BDU and OPU. The new software developed by Simrad provides a mechanism for the BDU to time tag the soundings before they are transmitted over the radios. The latency of the telemetry link does not affect the survey data. The time clock of the BDU can now be synchronized to an external time reference.

The data rate from the EM 950 was higher than expected. The higher data rate may be due to the conditions of the survey area, to recent changes in the software, or to operator settings on the EM 950. The information will be delivered to Simrad for further investigation.

The Arlan 620's work well with the EM 950. They do not lose data until their data buffers overflow. They do not send erroneous data or noise. They are very fast to re-establish the data link. When near the limits of their range and the antenna motion was causing data link failures, they would transfer data at full data rate during the fraction of a second that the antenna was near vertical and often kept up with the data rate from the EM 950.

There may be fringe zones past the limit of reliable radio ranges. The zones may be caused by multipath, antenna beam patterns or other phenomena. Further investigation may be required.

The range limits were shorter than desired, but several factors could be changed to improve the range.

Antenna height- The primary 7 db antenna on the Coastal Surveyor was not elevated as high as it would be on the mother ship. Antenna height has a significant effect on range.

Cable loss- The signal loss from the long antenna cables could be reduced by using shorter cables. The radio on the mother ship could be mounted in a weather proof enclosure on the antenna mast near the antenna.

Antenna types- The beam pattern of the antenna may be affecting the range. There may be low gain lobes causing problems at certain ranges.

RECOMMENDATION

Follow-on tests should be conducted in order to optimize system configurations to extend the reliable range to at least 3 miles. This could be done from a dockside antenna mast to extend the antenna height to the expected height of the mother ship and reduce the excessive antenna motion experienced during the sea trials. The roll rate of the intended mother ship is expected to be 5 degrees or less at sea state five. A small vessel could be used to simulate the Sea Lion. System optimization would include reducing antenna cable lengths to reduce signal attenuation and possible changes in antennas and antenna orientation.

FOLLOW-ON TESTS

The Contract Technical Manager agreed that follow-on tests should be conducted to improve the range of the high speed telemetry system. The test was conducted on August 4, 1994 at Cypremort Point, Louisiana with a vessel on Vermilion Bay.

INTRODUCTION

The purpose of this test was to increase the reliable range of the high speed telemetry system. Two approaches were taken. The first approach was to optimize system configuration to eliminate system losses to the lowest possible value. The second was to increase output power through the use of amplifiers.

The Contract Technical Manager, Mr. Harris, requested that we develop a link budget and range estimates to compare to the actual observed performance. Various information was gathered from experts in the field of radio transmission systems. EREPS was supplied to us by NRL. Also we gathered information from Telesystems,(ARLAN Bridge manufacturer), engineers. The link budgets and expected ranges calculated by each method varied. We conferred with Mr. Harris and Mr. Bourgeois (NRL) concerning the variances of the range prediction models. It was decided that EREPS data modified by indicating a 10db attenuation would most accurately predict the expected range. This is due to the characteristic that RADAR and narrow band radio power falls off as a function of range^2 verses range$^{3.6}$ for spread spectrum systems. The predicted ranges using these factors in EREPS were: 2.6 nmi for the 1 watt optimized system and 4.5nmi for the system amplified to 5 watts. The actual observed ranges are detailed below.

OPTIMIZED SYSTEM CONFIGURATION

A land based antenna mast was used to simulate the stability and height of the mother ship. Equipment configuration is as follows: A 7db antenna was mounted on an antenna mast with the center height of the antenna at 56 feet above water level. The Arlan Bridge was mounted on the antenna mast and connected to the antenna with 5 feet of low loss coax cable. The Arlan

Bridge was connected to a computer with 100 feet of thin net ethernet cable.

The Inland Surveyor, a 24 foot vessel, was used to simulate the Sea Lion. Equipment configuration is as follows: A 7 db antenna was mounted on the vessel with a center height of 11 feet above water level (the expected height for Sea Lions). The Arlan Bridge was connected to the antenna with 25 feet of low loss cable (the minimum length required for the Sea Lion).

AMPLIFIED SYSTEM CONFIGURATION

The land based configuration was initially set up with the Arlan Bridge on the ground and the Amplifier on the antenna mast interconnected by 100 feet of 75 ohm cable. The system was reconfigured when the amplifier failed to provide the expected results. It was suspected that the amplifier was not receiving sufficient control voltage through the 100 foot cable. The Arlan Bridge was mounted on the mast and connected to the amplifier with 3 feet of 75 ohm cable.

The system aboard the Inland Surveyor was left essentially the same with the exception of the 5 watt amplifier. The amplifier was connected to the antenna through 25 feet of low loss cable because the amplifier must remain in the electronics bay of the Sea Lion.

TEST RESULTS

The quality of the data link was evaluated by running tests with the Inland Surveyor at varying ranges from the base station. Two tests were run at each range.

The Link Test diagnostic provided in the firmware of the Arlan 620 was used to measure raw data link integrity at the lowest level. This test sends a user specified number of packets of a specified size to the remote radio, and the remote radio echoes the packets back to the sender. The diagnostic program reports the number of packets that were properly received by the remote system, and the number of those packets that were properly received from the remote system.

Figures 1 - 4 show the results of the Link Test. All results are shown for Arlan channel 8, which is a 344 Kbps channel centered around 915 Mhz.

Figure 1 represents the transmission quality from the simulated ORCA to the simulated mother ship using the 5 watt amplifier. The data link from the ORCA to the mother ship must be capable of carrying up to 150 Kbps of data. The link in the reverse direction will carry only a minimal amount of data. The radios provided consistent, reliable transmissions at ranges up to 5 nautical miles. The data became unstable past 5 nautical miles. It is expected that these results are dependent on ambient conditions.

Figure 2 represents the transmission quality from the simulated ORCA to the simulated mother ship using 1 watt Arlan radio transmitter. Transmission quality was acceptable for use with the Simrad EM 950 for ranges up to 2.5 nautical miles.

Figures 3 and 4 represent the transmission quality from the simulated mother ship to the simulated ORCA (the reverse link) with and without the 5 watt amplifier. The data points marked with circles indicate the lower quality transmissions observed when the long coax cable was installed between the power supply and the amplifier.

A file was transferred over the link using the Unix rcp program and data rates were calculated by timing the transfer. The rcp program uses TCP/IP protocol which relies on bi-directional communication to transfer the data and to return acknowledgements that each packet was received properly. The data rate depends on the link quality in both directions. The EM 950 uses UDP broadcasts to send data, and does not depend on a reverse channel for packet acknowledgments. Other data collection systems which may be installed on the ORCA may use the TCP/IP protocol.

Figures 5 and 6 represent the data transfer rate measured at varying ranges utilizing channel 8. The file transfers were fairly consistent and reliable for ranges up to 4 nautical miles when transmitting at 5 watts and 3 nautical miles when transmitting at 1 watt. The range for file transfers was shorter than for uni-directional data transfers as expected.

CONCLUSION

A high speed telemetry radio system has been configured and tested to be adequate for use with the Simrad EM 950 operating on ORCA vehicles. With 5 watt amplifiers, the system could be operated at ranges up to 5 miles under ambient conditions at the time of the test.

ORCA Spread Spectrum Telemetry Test

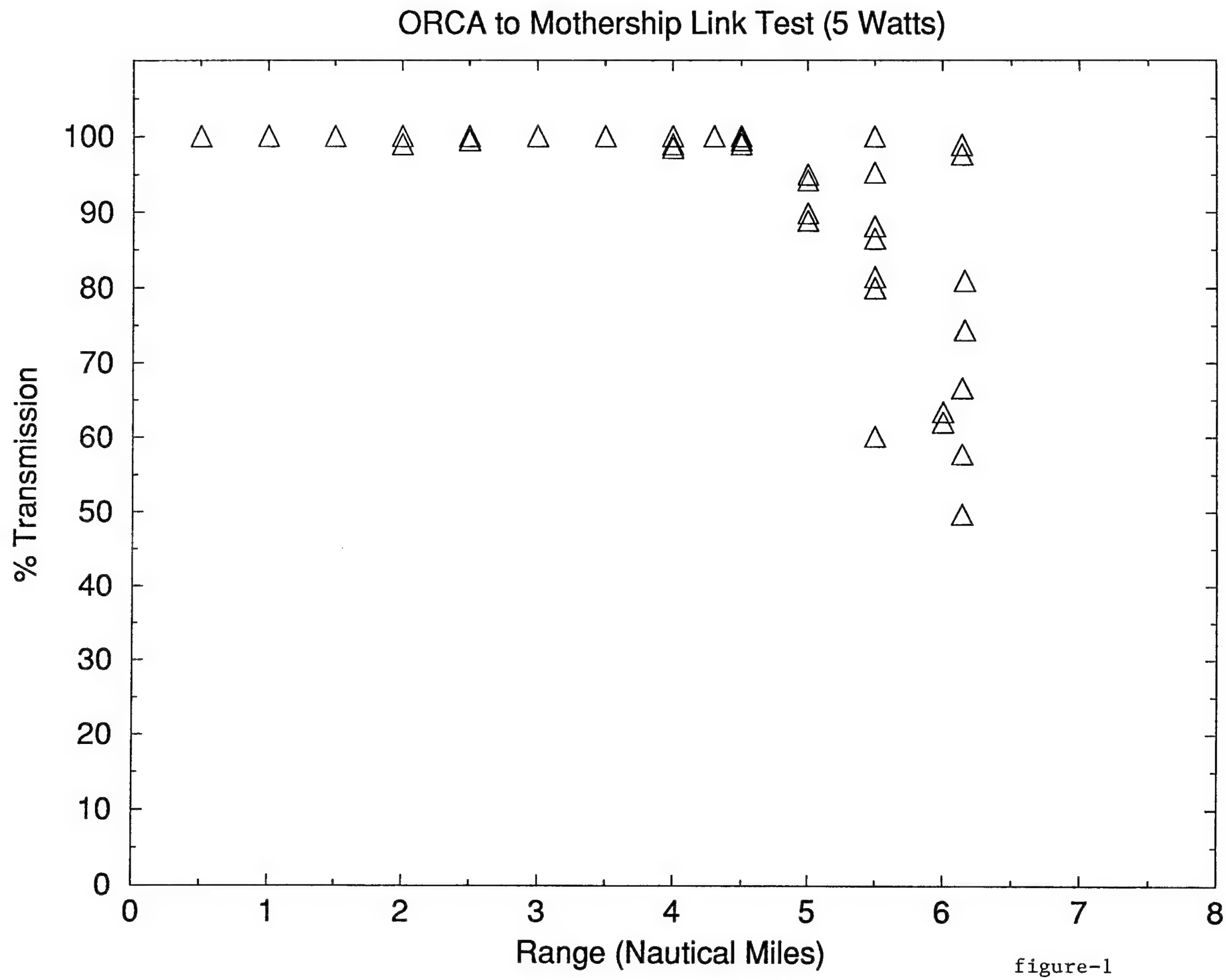


figure-1

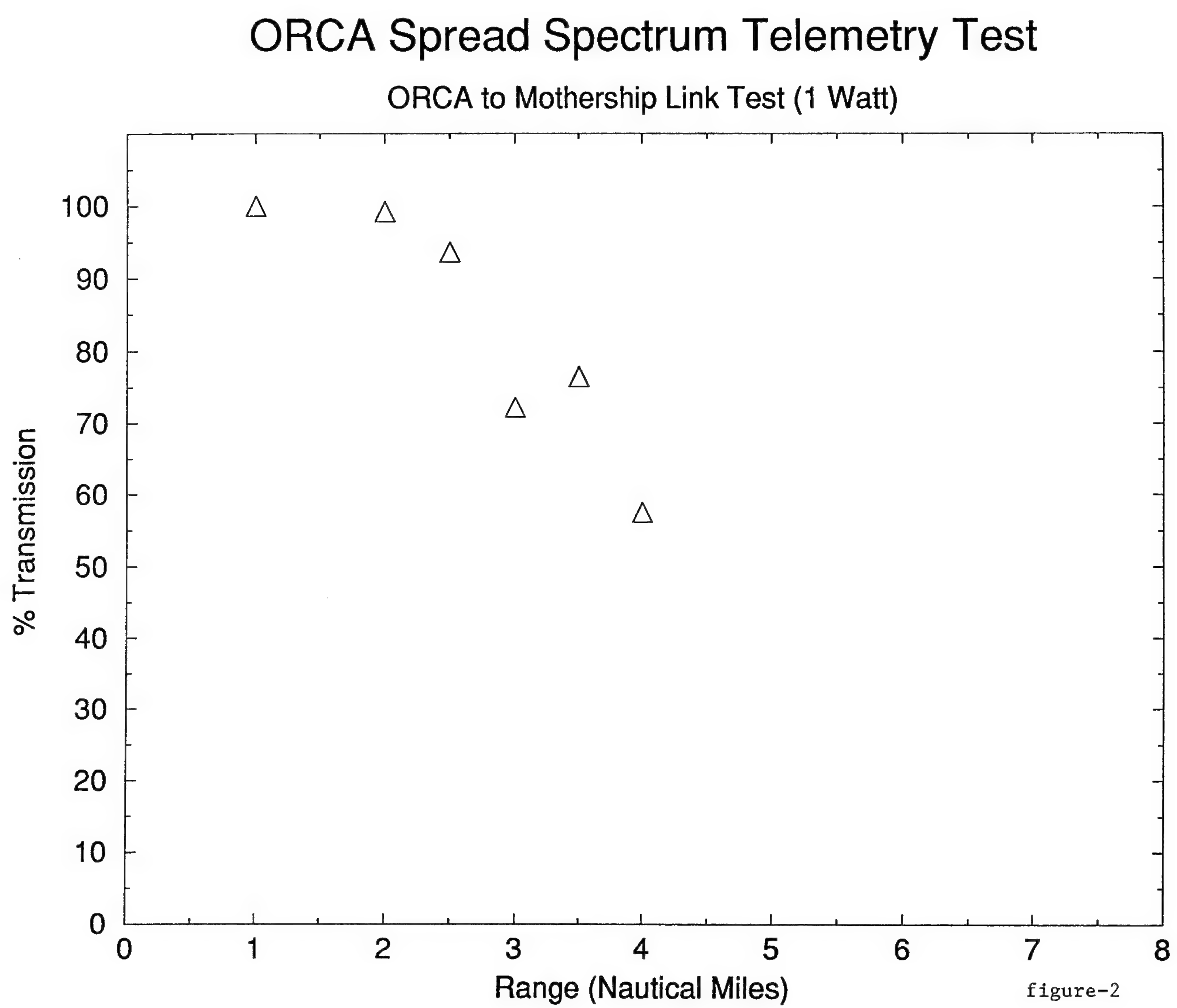
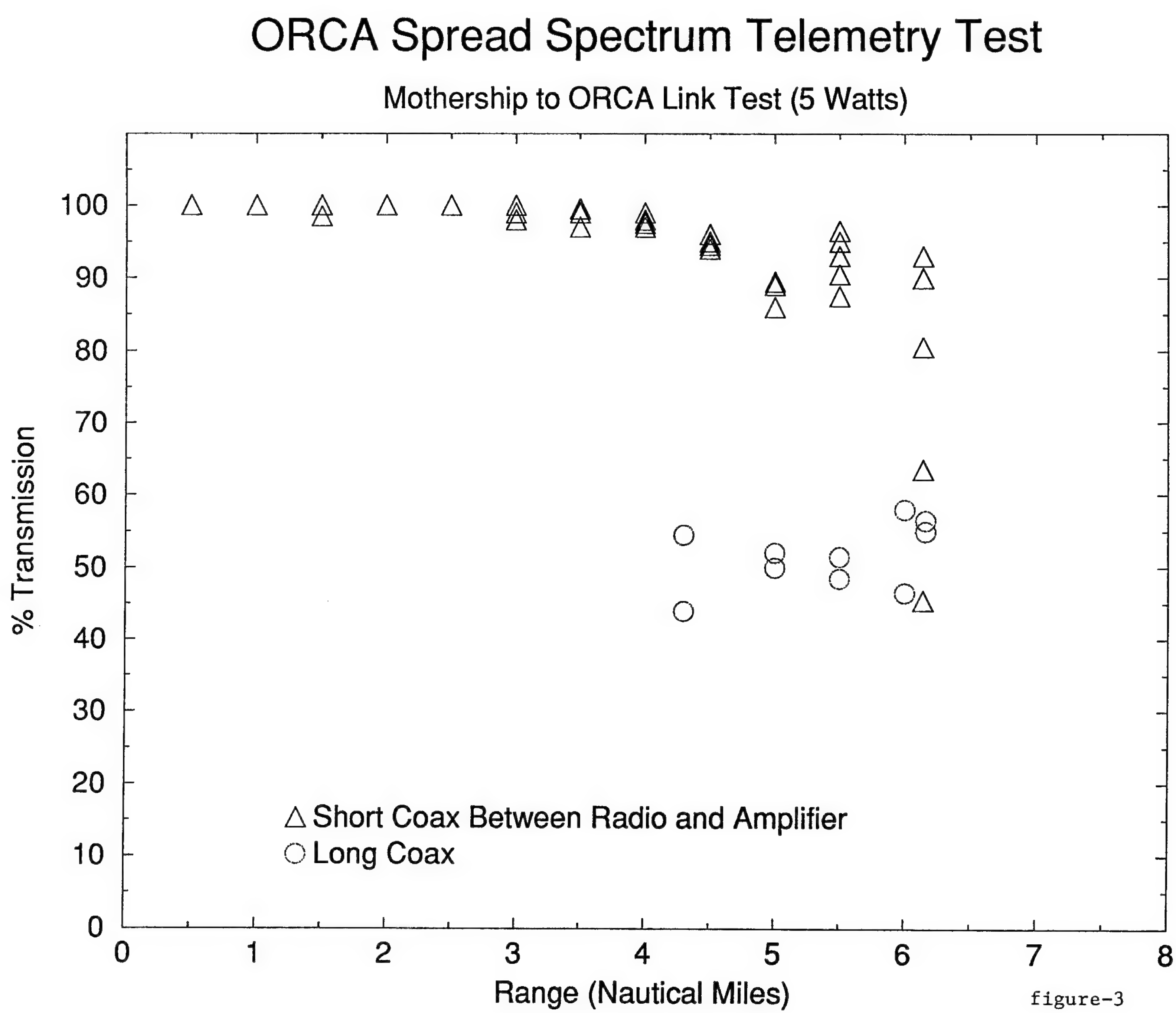

ORCA Spread Spectrum Telemetry Test
ORCA to Mothership Link Test (1 Watt)
% Transmission
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
Range (Nautical Miles)

figure-2



ORCA Spread Spectrum Telemetry Test
Mothership to ORCA Link Test (5 Watts)
% Transmission
100
90
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
Range (Nautical Miles)
△ Short Coax Between Radio and Amplifier
○ Long Coax

figure-3

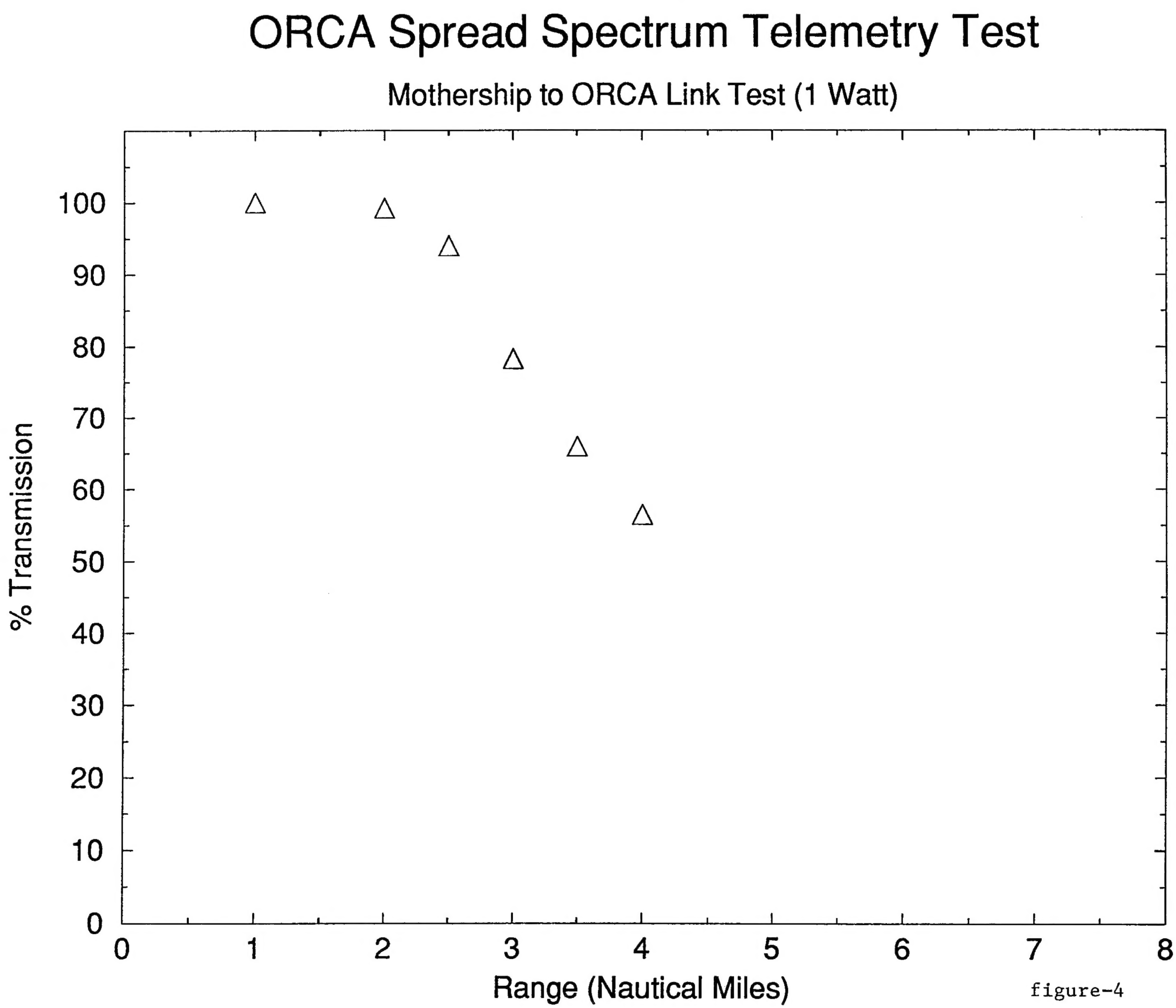

ORCA Spread Spectrum Telemetry Test
Mothership to ORCA Link Test (1 Watt)
% Transmission
0
10
20
30
40
50
60
70
80
90
100
0
1
2
3
4
5
6
7
8
Range (Nautical Miles)

figure-4

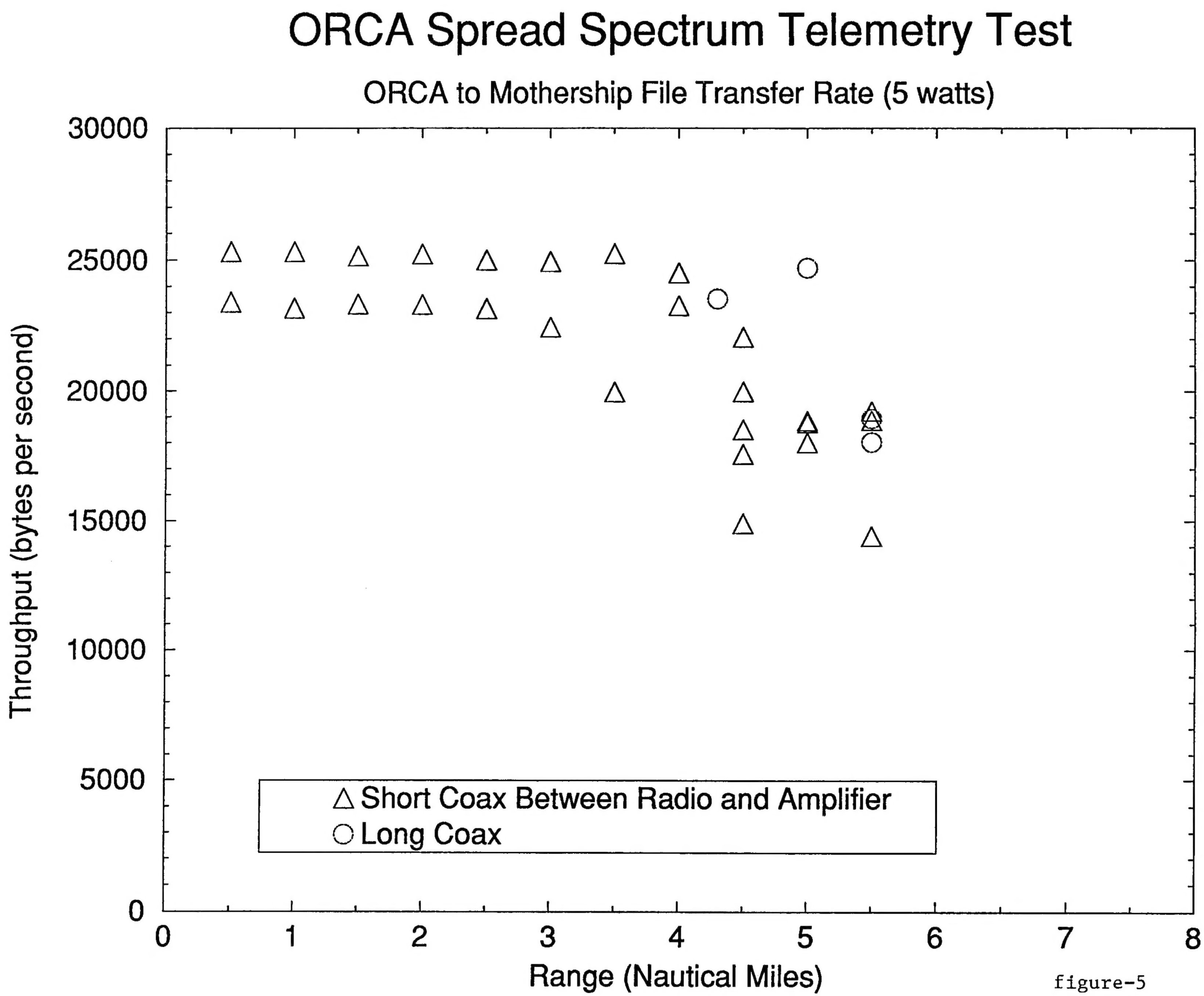
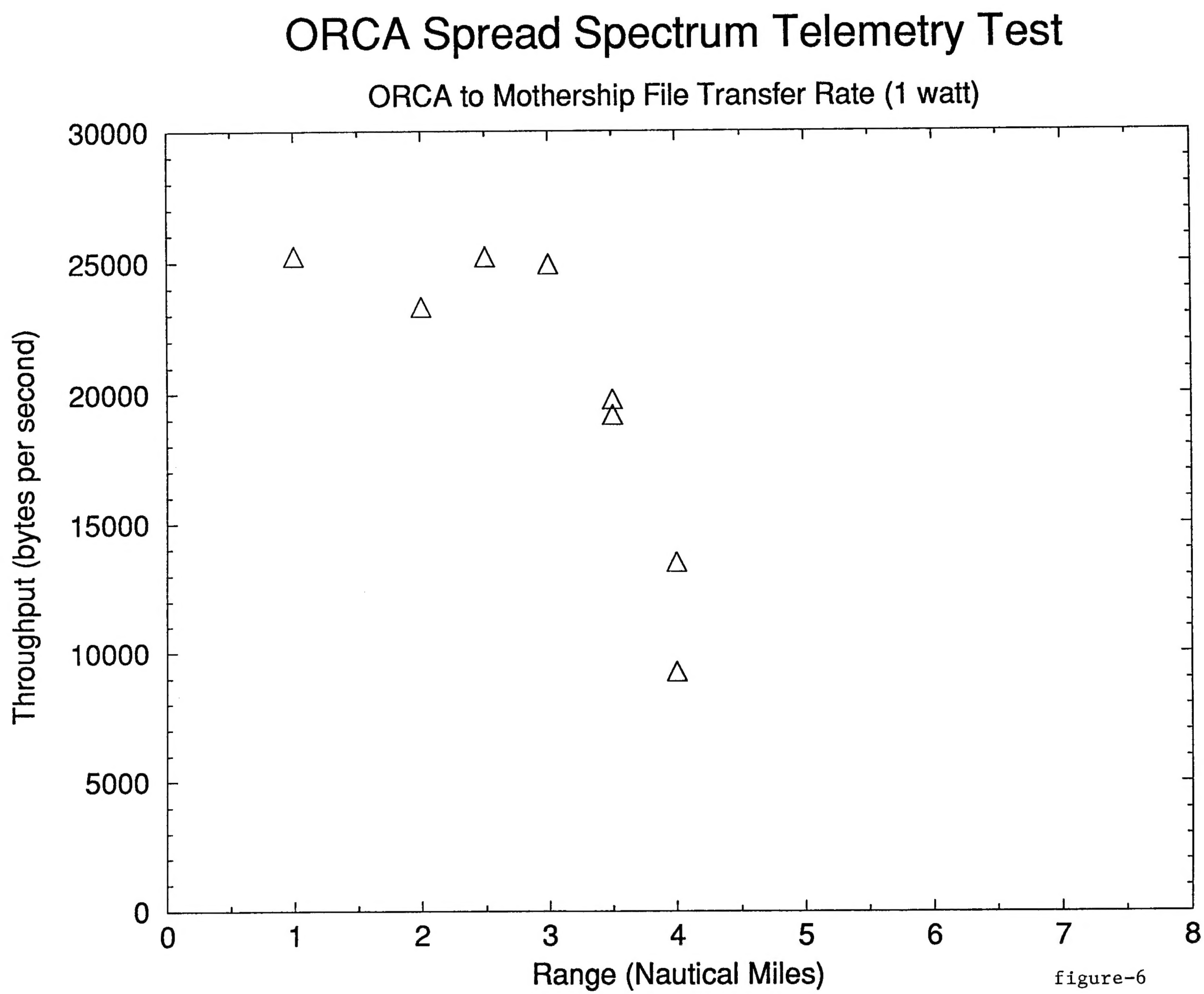

ORCA Spread Spectrum Telemetry Test
ORCA to Mothership File Transfer Rate (5 watts)
Throughput (bytes per second)
30000
25000
20000
15000
10000
5000
0
0
1
2
3
4
5
6
7
8
Range (Nautical Miles)
△ Short Coax Between Radio and Amplifier
○ Long Coax

figure-5


ORCA Spread Spectrum Telemetry Test
ORCA to Mothership File Transfer Rate (1 watt)
30000
25000
20000
15000
10000
5000
0
Throughput (bytes per second)
0
1
2
3
4
5
6
7
8
Range (Nautical Miles)
figure-6

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In support of the Naval Research Laboratory's Sea Lion program to instrument the remotely operated vehicles with multibeam bathymetry and imagery systems, it is necessary to demonstrate a telemetry system capable of handling the high data rates characteristic of this sensor suite at ranges of several miles on moving platforms. The telemetry system will have the capacity to deliver data at very high rates (possibly up to 8 megabits per second). Such a system will facilitate the relay of bathymetric data from the Sea Lions to a mother ship.

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